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DESIGN AND IMPLEMENTATION OF LOW COST MPPT SOLAR CHARGE CONTROLLER

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Abstract: *This paper deals with the implementation of a low-cost Maximum Power Point Tracker (MPPT) solar charge controller to constantly calculate and maintain the maximum amount of power from a solar panel using a DC/DC buck converter and a microcontroller. The MPPT algorithm has been implemented using an Arduino Uno with the incremental conductance method. The voltage and current of the panel are taken to the system using voltage and current sensors to track maximum power point. When irradiance and temperature are constant or slowly vary, the incremental conductance method tracks MPP steadily and calculates the operating point at which the battery is capable of producing maximum power. In this method, the controller provides the PWM signal to adjust the duty cycle to finally adjust the voltage. Adjustment is done by Buck converter. If the power increases, further adjustments in that direction are tried until power no longer increases. More over the system protected the battery from under charge and over charge. To do that two MOSFET (IRF250) and two Optocoupler (PC817) has been used. The proto type of the system has been developed and its performance has been studied. Finally, a cost analysis has been done to show its cost effectiveness.*

Keywords: Charge controller, Maximum power point tracker (MPPT), low cost, durability enhancement, photovoltaic plants.

1 Introduction

Solar, biomass & wind are the extended aspirant among the easily reached renewable energy sources in Bangladesh. Putatively, Bangladesh gets 69,751 TWh energy every year which is 3000 times greater than the traditional electricity generation [1]. In Bangladesh yearly, solar radiation has a regular power density of 100-300 W/m^2 which can produce 100 MW electricity with an area of 3-10 km^2 with a panel of 10% efficiency [2]. In a year with 6.8% (10,000 km^2) of the land of Bangladesh, per capita 3000 kWh electricity decree can be achieved [3]. The government of Bangladesh acmes the necessity of installing rooftop solar PV system due to the paucity of land. Researcher have found that 1000 MW of solar PV electricity with 75 W capacity of the solar module can be produced by the total accessible sunny rooftops area in Dhaka city which is 10.554 km^2. [4] The efficiency of solar PV decreases significantly because of non-linear characteristics of solar PV and atmospheric conditions which comprises the variation of irradiation as well as the different weather condition. [5]

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Depletion of power, more installation of PV panel, premature battery failure, capacity loss, lack of proper end-of-charge, higher voltage can be reduced by using MPPT solar charge controller with PV system. [6, 7] The buck converter is used as it has a linear voltage transfer function when functioning in Continuous Conduction Mode (CCM). It shortens things a lot, and the MPPT controller can be implemented by functioning directly on the converter duty cycle. The other topologies have a nonlinear voltage transfer function, and functioning directly on the duty cycle will produce erratic results, particularly at high duty cycles. In this case, the algorithm adapts the solar panel functioning voltage by using a proportional integral (PI) control loop, which directs the voltage to the preferred value [8-15].

2 Objectives

The objective of this paper is to design an incremental conductance algorithm based maximum power point tracker solar charge controller (MPPT). After the MPPT charge controller has been successfully implemented, a cost analysis will be done to compare it to the currently used MPPT charge controller. Therefore, implementing a cheap MPPT charge controller is also our main objective.

3 Limitation

- Two Hall Effect current sensor were used to measure the input and output current.
- The output of the current sensor was not very much accurate.
- Some error of the current sensor was observed while the reading was taken.

4 Methodology

- This research is conducted through two different stage first stage is software simulation and second stage is hardware implementation of the project.
- A buck converter is designed in proteus 8.1 professional.
- To design the buck converter a P-MOS driver was designed by using dual complementary Optocoupler.
- In hardware stage solar panel is connected to input of the buck converter and load connected to the output of the buck converter.
- Current and voltage sensor are connected both input and output to measure current and voltage.
- The measure voltage and current then fed to the system where an incremental conductance method is developed to calculate the maximum power and stay at the maximum point by changing the duty cycle.

5 Low cost MPPT solar charge controller

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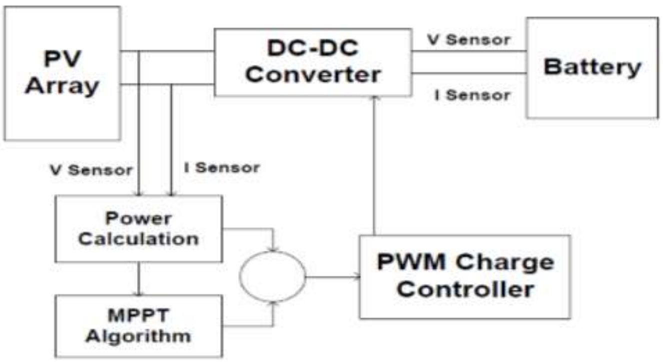

Figure 1: Block diagram of MPPT solar charge controller

The block diagram of entire system including PV module, MPPT charge controller and battery is shown above.

- The buck converter along with control circuit acts as MPPT charge controller.
- The PV module supply voltage to the battery through a buck converter.
- A control circuit is connected with the converter and sense the input and output through current and voltage sensors.
- The control circuit then compares this input voltage and current to the previous voltage and current to change the duty cycle of PWM signal in order to make the output constant.
- Thus, it can help to supply a constant power to the load which is exactly its maximum power.
- Incremental conductance algorithm is developed in Arduino to identify maximum power point and also set the set points.

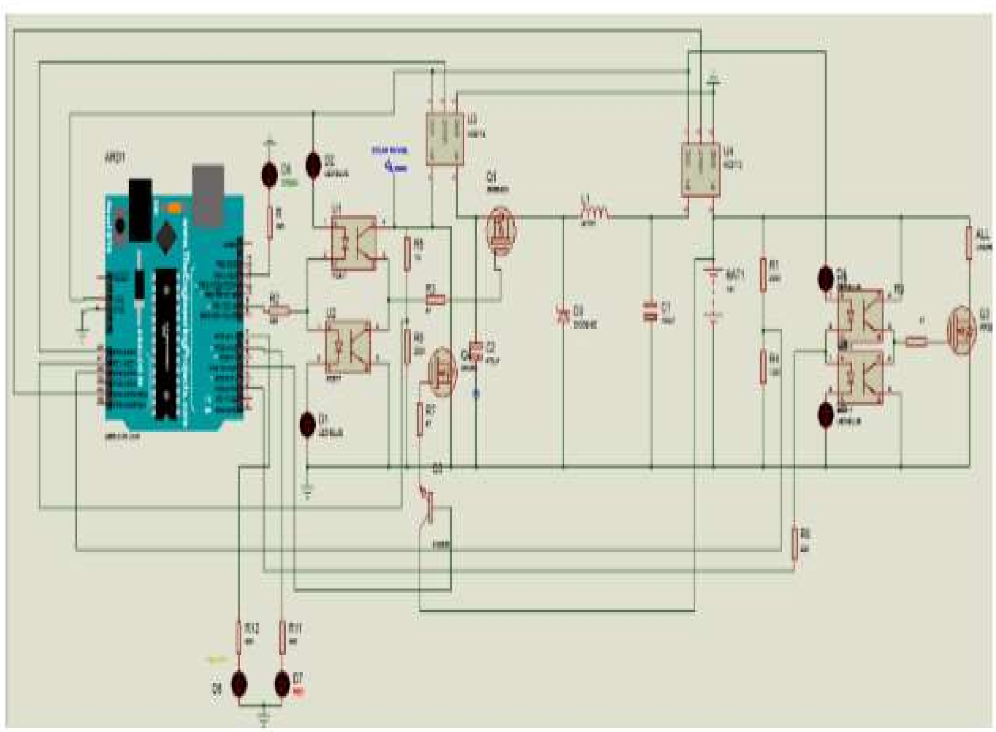

Figure 2: Schematic diagram of MPPT solar charge controller

6 The Implemented Hardware Circuitry

6.1 Component of the system

- Solar Panel
- Battery
- Load
- Microcontroller (Arduino Uno)
- MOSFET
- Inductor
- Capacitor
- Diode
- LED light
- Resistor
- Current sensor
- Connecting wires
- Optocoupler
- BJT

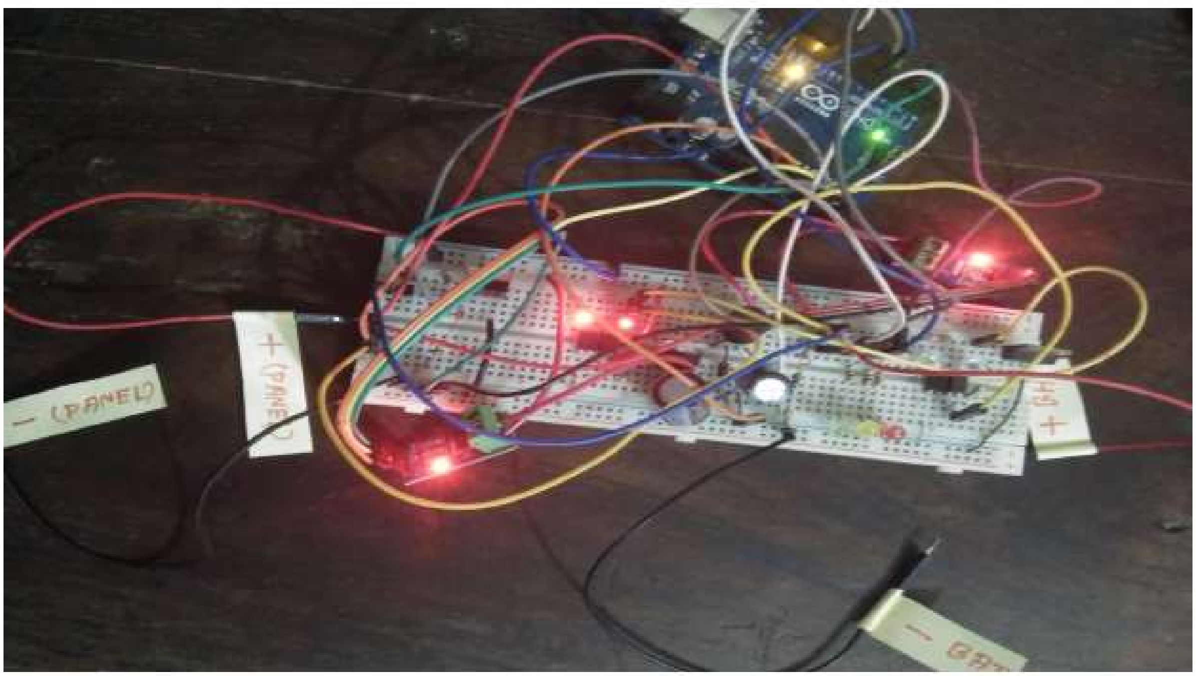

Figure 3: Implemented Hardware Circuit

6.2 Design Specification of Buck converter

The converter was designed on the base of input voltage, output voltage, and maximum power, switching frequency, inductor current ripple and output voltage ripple. The input voltage is chosen 27 V because most of the panels open circuit voltage is around 27 V. Output voltage is selected 15 V because battery can't be charged with high voltage and battery voltage can be reached at maximum 14.4V. The hardware circuit was designed for 500W. This is only for a prototype design. This device

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can be design over kW range.

Input voltage = 27 V

Output voltage= 15 V

Max power = 500 W

Switching frequency =15 KHz

Inductor current ripple =30 %

Output voltage ripple= 10 mV

Duty cycle D = $\frac{\text{Vout}}{\text{Vin}} = \frac{17}{27} = 0.55$

$\Delta I = \frac{\text{Max power}}{\text{Output voltage}} * 30\% = \frac{500}{15} * 0.3$ =10A

Inductor L:

$L = \frac{\text{Vout}(1-D)}{f*\Delta I} = \frac{15(1-.55)}{15*\frac{500}{15}*0.3} = 45$ mH

$I_{peak} = I_{out} + \frac{.3*\text{Iout}}{2} = 1.15*\frac{500}{15} = 38.33$ A

Capacitor C:

$\Delta V_c = \frac{\text{Vout}(1-D)}{8*C*L*f^2}$ => $C = \frac{1-D}{\frac{\Delta VC}{\text{Vout}}*8*L*f^2} = \frac{1-0.55}{\frac{10}{15}*8*47*15^2} = 8\ \mu F$

Power loss in diode P_D:

$P_D = 0.7*38.3*(1-(\frac{15}{27})) = 12$ W

6.3 Voltage Sensor

➢ The voltage inputs from the panel and the battery must be "stepped down" by using voltage division principle.

➢ The node voltages between the two resistors connected to the panel is fed to one ADC pin (AN1). Similarly, the node voltages from the resistors connected to the battery are connected to AN2.

➢ The ADC of the microcontroller divides these analog inputs into 1024 quantized levels.

➢ These values are 0 (for 0V input) and 1023 (for 5V input). In this way, voltage sensing of the panel and battery is achieved.

6.4 Current Sensor

➢ To read the current supplied by the PV module a Hall Effect current sensor (acs712) is used.

➢ The device includes an on-chip Hall voltage generator for magnetic sensing, a comparator that amplifies the Hall voltage, and a Schmitt trigger to provide switching hysteresis for noise rejection, and output driver with pull-high resistor.

➢ If a magnetic flux density larger than threshold βOP, D0 is turned ON (low). The output state is held until a magnetic flux density reversal falls below βOP causing DO to be turned OFF (high) [Pi Labs]. In this way, the sensor detects the magnetic flux produced by the analog input, and reads current as a voltage.

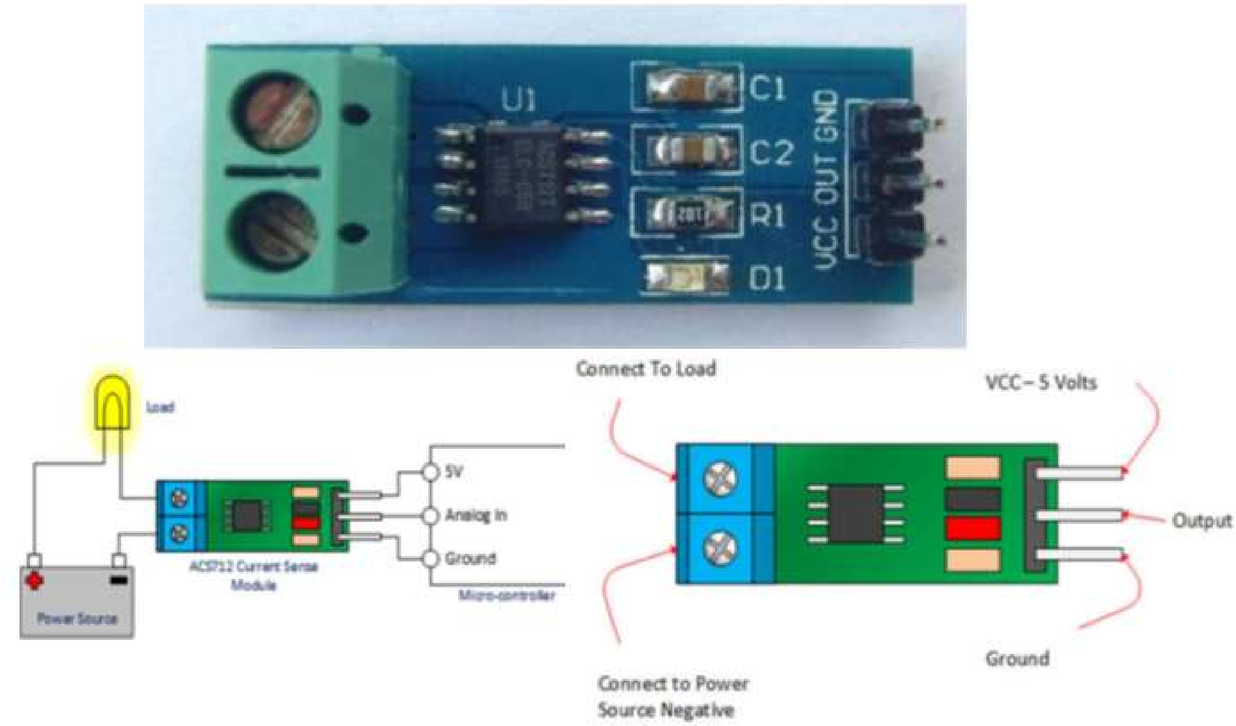

Figure 4: Acs712 current sensor pin diagram and connection

6.5 MOSFET Driver

➢ A MOSFET driver is required as the microcontroller cannot supply enough current to charge the MOSFET to turn on a power MOSFET.

➢ The PWM signal will be applied with respect to MOSFET source using buck converter.

➢ Two Optocoupler were used to form the driver.

➢ The advantage of this driver is that it is cheap compared to available pull up driver in the market which decreases cost of the circuit further.

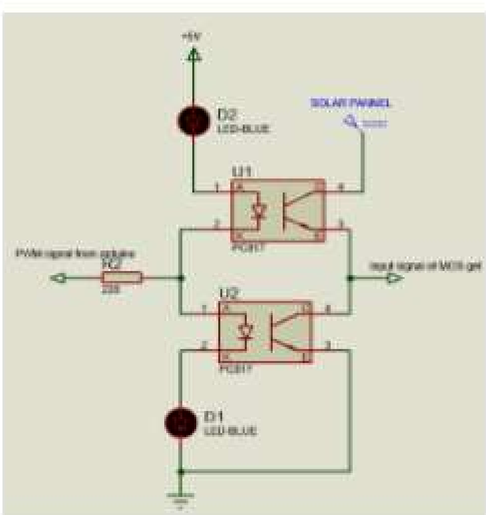

Figure 5 MOSFET driving circuit

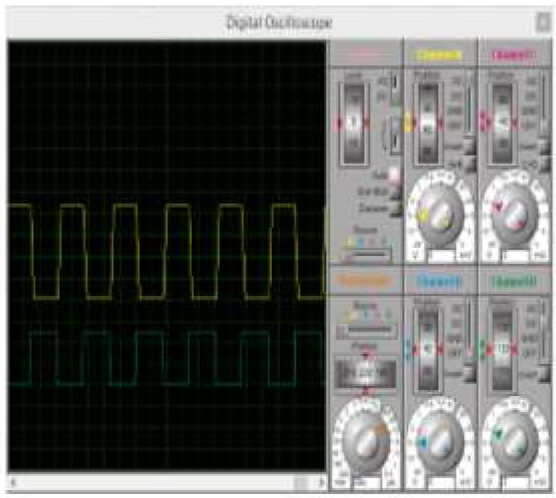

Figure 6: Gate driving input (green signal f=15 kHz) and output signal (yellow signal f=15 kHz).

6.6 Load Control Circuit

- Load control circuit is used to protect the battery from over discharge.
- Dual complementary Optocoupler, two led, two resistors and one IRF250 MOSFET are used to form load control circuit.
- When logic input is low then output is high which turns on the MOSFET and load is connected to the battery.
- When logic input is high then output is low that mean battery voltage is low and load is disconnected from the battery.

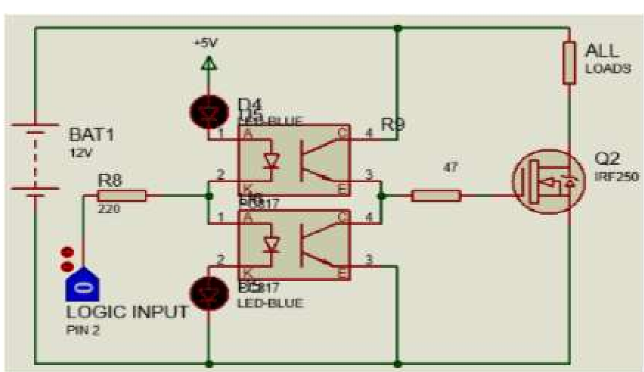

Figure 7: Load control circuit diagram.

6.7 Array Control Circuit

- One BJT, one resistor and one IRF250 MOSFET is used to form array control circuit.
- When logic input from pin 4 is high, MOSFET is ON and its short circuit the panel.

- When logic input is low MOSFET is OFF and charge the battery.

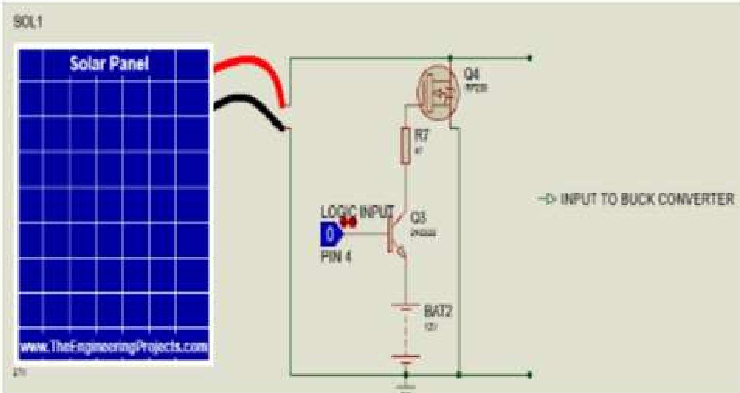

Figure 8: Array control circuit diagram.

7 Data Observation and Financial Analysis

Table 1 Buck converter output voltage measurement for different duty cycle (input voltage=22 V)

Duty Cycle (%)	Input Voltage(V)	Output Voltage(V)
10	22	4.3
20	22	7.7
30	22	10.7
40	22	13
50	22	14.9
60	22	16.2
70	22	17.2
80	22	18
90	22	19.4
97	22	21.3

Table 2 Buck converter output voltage measurement for different duty cycle (input voltage=17V)

Duty Cycle (%)	Input Voltage (V)	Output Voltage (V)
10	17	3.7
20	17	6.4
30	17	8.6
40	17	10.4
50	17	11.7
60	17	12.8

70	17	13.5
80	17	14.1
90	17	15.3
97	17	16.7

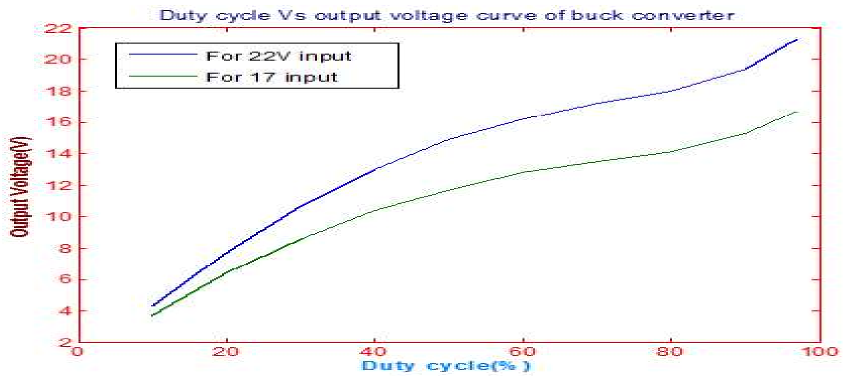

Figure 9: Output voltage vs Duty cycle of buck converter

Table 3 Tested Panel Specification

Power (max) (W)	Cell Type	Vmp (V)	Imp (A)	Voc (V)	Ish (A)	Tilt Angle (degree)	Duration (month)
55	Polycrystalline	17.4	3.15	21.7	3.45	20	May & June

Table Data collected in sunny weather

Input voltage(V)	Input current(A)	Output voltage(V)	Output current(A)	Power(w)
15.82	1.98	12.8	2.4	31.3
15.98	2.16	12.8	2.6	34.5
16.41	2.39	12.9	2.78	39.2
16.88	2.37	12.8	2.91	40
16.92	2.27	13	2.8	38.41
16.96	2.24	12.75	2.49	38
16.97	2.38	13.2	2.53	40.3
17	2.44	13	2.7	**41.48***
17.02	2.27	13.5	2.51	38.6
17.04	2.17	13.9	2.55	37
17.09	2.25	13	2.85	38.45
17.16	2.35	13.7	2.72	40.3
17.2	2.16	13.3	2.78	37.5

***Pmax**

Table 4: Data collected in partly sunny weather

Input voltage(V)	Input current(A)	Output voltage(V)	Output current(A)	Power(w)
15.65	1.64	12.5	2.1	25.70
15.7	1.73	12.56	2.1	27.16
16.67	1.61	12.5	2.2	26.88
16.71	1.66	12.7	2.27	27.77
16.67	1.8	12.7	2.3	30
16.86	1.82	12.9	2.39	30.65
17.66	1.91	12.84	2.41	33.67
17.61	1.96	13.01	2.63	34.61
17.72	1.98	13.14	2.55	**35.15***
17.75	1.92	12.76	2.16	34.01

***Pmax**

Table 5: Data collected in cloudy weather

Input voltage(V)	Input current(A)	Output voltage(V)	Output current(A)	Power(w)
14.22	1.1	12.5	1.29	15.7
14.30	1.1	12.4	1.27	15.73
14.35	1.1	12.5	1.26	15.78
14.36	1.1	12.75	1.29	15.72
14.47	1.15	12.6	1.30	16.64
14.59	1.2	12.8	1.27	**17.51***
14.13	1.14	12.8	1.30	16.1
13.7	0.95	12.35	0.93	13
13.71	0.85	12.32	1.10	11.66

***Pmax**

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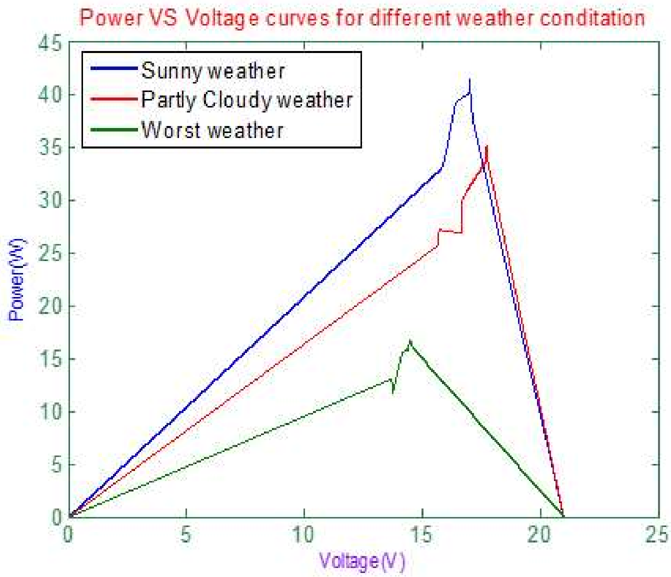

Figure 10: Power vs Voltage curve for different irradiation

Test with DC voltage source with 30 W load

Table 6: Input and output voltage data for 22 V DC source

Input voltage(V)	Input current(A)	Output voltage(V)	Output current(A)	Duty cycle	Pmax(W)	Efficiency (%)
22	0.73	11	1.1	147	16.79	
22	0.76	11.5	1.29	147	18.06	
22	0.73	11.7	1.34	157	19.2	
22	0.77	12	1.37	167	19.3	
22	0.81	12.2	1.40	167	19.6	
21.9	0.84	12.9	1.40	177	19.6	
21.9	0.87	12.9	1.5	177	21	
21.8	0.79	13	1.49	177	20.86	
21.86	0.98	13.3	1.41	187	19.74	
21.86	0.93	13.8	1.66	197	23.24	**Overall Efficiency Around 90%**
21.86	1.05	13.8	1.59	197	22.26	
21.80	1.11	14	1.73	207	24.22	
21.80	1.23	14.1	1.88	217	26.32	
21.80	1.44	14.3	1.78	227	29.46	
20.78	1.35	14.4	1.81	237	27.55	
20.78	1.38	14.4	1.78	247	27	

Table 7: Input and output voltage data for 17 V DC Source

Input voltage (V)	Input current (A)	Output voltage (V)	Output current (A)	Duty cycle	Pmax (W)	Efficiency (%)
16.69	0.61	10	0.86	137	10.07	
16.82	0.59	10	0.87	147	9.96	
16.71	0.62	10	0.84	147	10.35	
16.70	0.68	10	0.94	157	11.29	
16.68	0.71	10	0.92	167	11.86	
16.61	0.67	10	0.91	177	11.07	Overall Efficiency Around 90%
15.51	0.74	11	1	187	12.22	
16.54	0.79	13	1.08	197	12.98	
16.52	0.86	13	1.21	207	14.17	
16.50	0.98	13	1.37	217	15.91	
16.43	1.16	14	1.4	227	18.98	
16.43	1.21	14	1.41	237	19.96	
16.41	1.16	14	1.41	247	18.98	

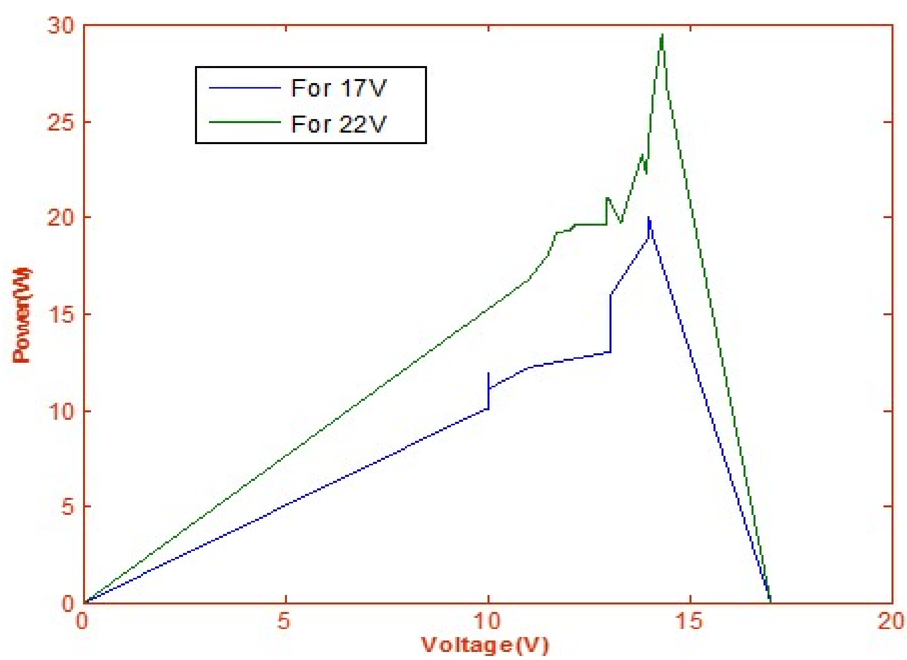

Figure 11: Power vs Voltage curve for different dc voltage

7.1 Set Points of Charge Controller

Table 8 Actual values of set points of charge controller

Battery voltage (V)	Charge controller set point

12.55	LRV (Load Reconnect Voltage)
14.50	VR (Voltage Regulation)
12.98	ARV (Array Reconnect Voltage)
10.82	LVD (Low Voltage Load Disconnect)

7.2 Financial Analysis

The production cost of the circuit is around 950 BDT which is really cheap compare to existing market MPPT charge controller.

Table 9: Cost analysis of the charge controller

Equipment	Quantity	Per unit price (BDT)	Total Price (BDT)
Arduino Board	1	350	350
MOSFET	3	40	120
Inductor	1	5	5
Capacitor	2	5	10
Diode	1	5	5
LED Light	8	2	16
Resistor	4	5	2
Current sensor	2	150	300
Connecting wires	-	30	30
Optocoupler	4	10	40
Miscellaneous	-	-	72
Total			**950**

8 Findings

- At every condition it extracting the maximum power from the panel.
- Automatically it adjusts the maximum power point when the radiation is changed.
- For 30W load at two different voltage level, the maximum power point is extracted by changing the duty cycle.

9 Recommendations

It is well known that various types of methods are used for generating the electricity like Thermal Power plants (Nuclear, Coal, petroleum etc.), Hydro (water) power plants, but it is non-renewable resources and also harmful for humans as well as environment. As many types of other charge controllers like PWM etc. also available, but due to low efficiency it cannot be used completely by the consumers. Hence there is need to develop more other cheap and effective MPPT algorithms, so that almost 100% efficiency can be achieved. Here are the some that can be future research papers:

1. MPPT operating APP: An application of operating MPPT by the help of smartphones can so be made operate from whenever via the Internet.
2. DC-DC running loads: DC from MPPT can be taken directly and DC load can be run. DC loads

helps to consume low electricity.
3. Energy Management: There is need to manage energy when these algorithms are developed.

10 Conclusion

The MPPT solar charge controller was implemented to its modest and most elementary components to certify the consistency, and cost effectiveness. Also, additional program was also established to familiarize the set points. The enactment of the controller is effectually evaluated by collecting raw data for different weather condition as well as for different output voltages by varying duty cycle. In addition, the features and limitations of the system is described in the manuscript. After perceiving and investigating the response of the system, it can be concluded that the implemented system works impeccably with high accuracy with a reasonable price.

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